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EFFECT OF NANO-SILICA ON CONCRETE CONTAINING METAKAOLIN

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ABSTRACT

In this paper the results of an experimental investigation on the use of Metakaolin (MK) and Nano-Silica (NS) on various properties of concrete are presented. Metakaolin and Nano-Silica are used as partial replacement of cement for the preparation of concrete. In the present investigation initially cement is partially replaced by Metakaolin 5% and 10% by weight. Further investigation is carried out by combined replacement of Metakaolin at 5% and 10% with Nano-Silica at 1%, 2% and 3% by weight of cement. For structural applications the various properties, such as compressive strength, split tensile strength, modulus of elasticity and flexural strength of M25 grade concrete containing MK and NS are evaluated and the results are compared with the controlled concrete. Based on the test results, it can be observed that concrete prepared with a combination of 5% MK and 2% NS indicated increased strength compared to the controlled concrete. Hence, it can be concluded that concrete prepared with 5% MK and 2% NS combination can be recommended for the structural applications. The increase in the strength properties of concrete is due to the availability of additional binder in the presence of MK and NS.

Key words: Metakaolin, Nano-Silica, Cement Replacement, Modulus of Elasticity and compressive Strength.

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1. INTRODUCTION

The construction industry uses concrete to a very large extent. Cement is one of the important components of concrete. The demand for Portland cement is increasing in developing countries. Portland cement production is one of the major reasons for CO_2 emissions into atmosphere. It is due to the use of fossil fuels, including the fuels required to generate electricity during cement manufacturing process. Hence to reduce the consumption of cement, the application of pozzolana materials is increasing day-by-day in the form of partial replacement for concrete preparation. The use of pozzolana's for making concrete is considered efficient, as it allows the reduction of the cement consumption while improving the strength and durability properties of the concrete.

Cement is one of main constituents of concrete and its main product of hydration i.e. C-S-H is of nano structure. The strength and durability characteristics of concrete depend on the quality of C-S-H gel. Silica is one of the most important components in concrete's micro-structure quality improvement. Therefore, extensive research is directed towards the performance of pozzolana concrete in recent years.

Metakaolin when used as a partial replacement substance for cement in concrete, it reacts with $Ca(OH)_2$ one of the by-products of hydration reaction and results in additional C-S-H gel leading to increase in various strength properties of concrete. It also reduces the hardened concrete permeability. Hence by partially replacing Portland cement with Metakaolin not only reduces carbon dioxide emissions into the atmosphere during the production of cement but also increases the service life of buildings.

The mechanical and durability properties of concrete are mainly dependent on the gradually refining the structure of hardened cement paste and the gradually improving paste–aggregate interface. Nano-Silica, a new pozzolanic material produced synthetically, in the form of water emulsion of Ultra-Fine Amorphous Colloidal Silica (UFACS), is better than silica fume due to the higher content of amorphous silica. Impermeability and strength characteristics of concrete can be improved by using Nano-Silica. In the present research work, an attempt has been made to assess the combined application of Metakaolin and Nano-Silica on the performance of concrete

2. OBJECTIVE

The main objective of the present experimental investigation is to obtain the influence of the combined application of Metakaolin and Nano-Silica on various strength properties of M25 grade concrete. Combination of 5% and 10% of Metakaolin and 1%, 2% and 3% of Nano-Silica by weight of cement replacement is adopted. Using different proportions of Metakaolin and Nano-Silica compressive strength, split tensile strength, modulus of elasticity and flexural strength tests were performed on concrete specimens and the results were compared with the controlled concrete.

3. EXPERIMENTAL INVESTIGATION

3.1 Materials

3.1.1 Cement

In the present investigation Ordinary Portland Cement (OPC) of 43 Grade confirming to IS specifications was used. The specific gravity of the cement is 3.15.

3.1.2 Fine aggregate

Locally available river sand (Zone - II) confirming to IS specifications with fineness modulus of 2.94 was used as the fine aggregate in the concrete mix.

3.1.3 Coarse Aggregate

Machine crushed aggregate confirming to IS 383-1970 obtained from the local quarry is used as coarse aggregate. The nominal sizes of coarse aggregate adopted in the present investigation were 20 mm and 12 mm. The properties of coarse aggregate and fine aggregate used in the present investigation are shown in the Table. 1

Table.1: Properties of CA and FA

Property	Coarse Aggregate	Fine Aggregate
Specific Gravity	2.64	2.66
Water Absorption (%)	0.25	1.10

3.1.4 Metakaolin

Metakaolin is a refined kaolin clay that is fired (Calcinated) under carefully controlled conditions to create an amorphous alumina silicate that is reactive in concrete. Compared to cement, the particle size of Metakaolin is very finer. It acts as an excellent pore-filling material. Metakaolin is known as supplementary cementitious material. The properties of Metakaolin used in the present investigation are shown in the Table. 2

Table.2: Properties of Metakaolin

S.No.	Characteristics	Actual Analysis Result
1	Sio_2	52-55%
2	Alumina (Al_2O_3)	40-43%
3	Ferric oxide(Fe_2O_3)	<1
4	Bulk density	350 gm/liter
5	Moisture	0.23%
6	Appearance	white powder
7	PH	6.59
8	Residue on 325 Mesh	0.1%
9	50% particles below	1.74µ
10	Specific gravity	2.61

3.1.5 Nano-Silica

Nano-Silica is a new pozzolanic material in the form of water emulsion of colloidal silica. It appears to be potentially better than silica fume for the higher content of amorphous silica (> 99%) and the reduced size of its spherical particles (1-50 *nm*). In the present experimental investigation cement is replaced by 1%, 2% and 3% of Nano-Silica by weight. The properties of Nano-Silica are shown in the Table.3.

Table 3 Properties of Nano-Silica

S.No.	Characteristics	Actual Analysis
1	Nano solids	30-32%
2	PH	9.0-10
3	Specific Gravity	1.20-1.22
4	Texture	White Milky Liquid
5	Dispersion	Water

3.1.6 Water

Potable water is used for casting and curing concrete test specimens. Water used is free from acids, organic matter, suspended solids and impurities which when present can adversely affect the strength of concrete.

3.2 Concrete Mix Proportion

In the present experimental investigation the influence of Metakaolin as partial replacement of cement and combined application of Metakaolin and Nano-Silica as partial replacement of cement on M25 grade of concrete is studied.

M25 grade of concrete was designed as per the Indian Standard code of Practice. The various ingredients for one cubic meter of M25 grade concrete is shown in Table 4. As the Nano-Silica is available in the colloidal form, the quantity of water required for making concrete is adjusted to account for the water available in colloidal Nano-Silica.

Table 4 Quantities of Ingredients per cum of M25 Grade Concrete

Concrete	Cement (Kg)	Metakaolin (Kg)	Colloidal Nano-Silica (lit)	Water (lit)		w/c	Fine Aggregate (Kg)	Coarse Aggregate (Kg)
				water available in NS	Added water			
Control	326	0	0	0	163	0.5	742	1210
MK 5%	309.7	16.3	0	0	163	0.5	742	1210
MK 10%	293.4	32.6	0	0	163	0.5	742	1210
MK 5% +NS 1%	306.44	16.3	10.52	7.26	155.74	0.5	742	1210
MK 5% +NS 2%	303.18	16.3	21.03	14.51	148.49	0.5	742	1210
MK 5% +NS 3%	299.92	16.3	31.55	21.77	141.23	0.5	742	1210
MK 10% +NS 1%	290.14	32.6	10.52	7.26	155.74	0.5	742	1210
MK 10% +NS 2%	286.88	32.6	21.03	14.51	148.49	0.5	742	1210
MK 10% +NS 3%	283.62	32.6	31.55	21.77	141.23	0.5	742	1210

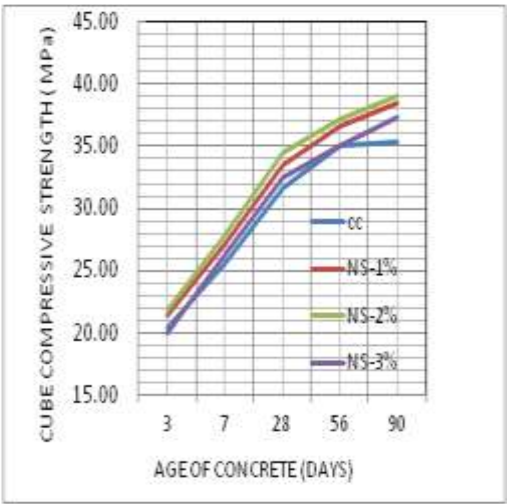
3.3 Test Specimens

Concrete test specimens consist of 150mm x 150mm x150mm cubes, cylinders of 150mm diameter and 300mm height and Prisms of 150mm x 150mm x 700mm. Concrete cube specimens were tested at 3, 7, 28, 56 and 90 days of curing to obtain the compressive strength of concrete. Cylindrical specimens of 150mm diameter and 300mm height were tested at the age of 28 days to obtain the split tensile strength of concrete and modulus of elasticity of concrete. The prisms were tested at the age of 28 days to obtain the flexural strength of concrete.

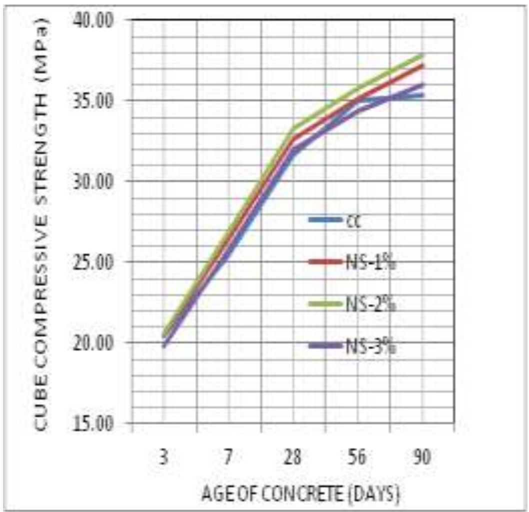
4. RESULTS AND DISCUSSION

4.1 Compressive Strength

The variation of the cube compressive strength at different periods of curing of M25 grade concrete prepared using the various proportions of Metakaolin and Nano-Silica is shown in Fig.1. Each value of the cube compressive strength indicates the average of three test results. It can be observed that the compressive strength of Metakaolin and Nano-Silica concrete exhibits more than that of controlled concrete.



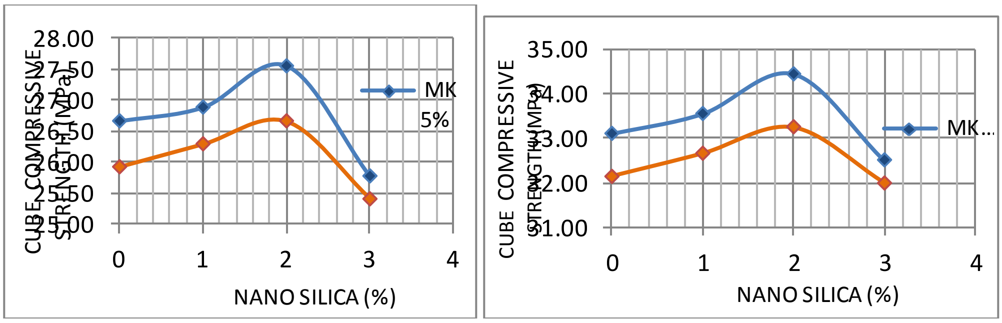
(i) MK (5%)



(ii) MK(10%)

Figure 1 Variation of Cube compressive strength of M25 grade concrete with age for different percentages of Metakaolin(MK) and Nano-Silica(NS).

The variation of 7 days and 28 days cube compressive strength of M25 grade concrete prepared with Nano-Silica containing different percentages of Metakaolin is also shown in Fig.2 The compressive strength of concrete initially increases up to 2% of Nano-Silica and then the strength decreased with increase in Nano-Silica for 5% and 10% Metakaolin. This can be attributed to the non-availability of sufficient quantity of C-S-H gel. The 7 days and 28 days cube compressive strength of M25 grade control concrete is 25.48 N/mm^2 and 31.63 N/mm^2 respectively. The increase in 7 days and 28 days cube compressive strength of concrete with 2% Nano-Silica and 5% Metakaolin combination is 9.34% and 8.90% respectively.



(a) 7 days Cube compressive Strength (b) 28 days Cube compressive Strength.

Figure 2 Variation of 7 days and 28 days Cube Compressive Strength of M25 grade concrete with different percentages of Metakaolin(MK) and Nano-Silica(NS).

4.2 Split Tensile Strength:

The variation of Split tensile strength of M25 grade concrete prepared using 5% and 10% Metakaolin with increase in Nano-Silica is shown in Fig.3. The Split tensile strength of M25 grade of controlled concrete is 2.96 N/mm^2. The split tensile strength of Metakaolin concrete initially increases up to 2% of Nano-Silica and with further increase in the Nano-Silica content the split tensile strength decreases. Similar trend is observed with the concrete containing 5% and 10% Metakaolin. The increase in split tensile strength of 5% Metakaolin concrete containing 2% Nano-Silica compared with conventional concrete is 8.44%.

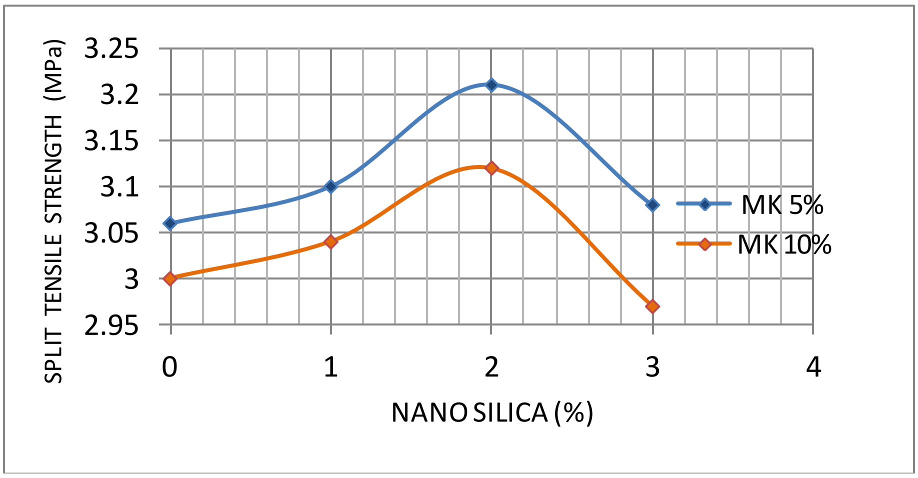


Figure 3 Variation of Split Tensile Strength of M25 grade concrete with different percentages of Metakaolin (MK) and Nano-Silica (NS).

4.3 Modulus Elasticity:

The variation of Modulus of Elasticity of M25 grade concrete containing Metakaolin with increase in Nano-Silica is shown in Fig.4. The Modulus of Elasticity of M25 grade of controlled concrete is 27100 N/mm^2 . The Modulus of Elasticity of concrete initially increases up to 2% of Nano-Silica and with further increase in the Nano-Silica content the Modulus of Elasticity decreases. Similar trend is observed with the concrete containing 5% and 10% Metakaolin. The increase in Modulus of Elasticity of Concrete with 5% Metakaolin and 2% Nano-Silica compared with conventional concrete is 7.80%.

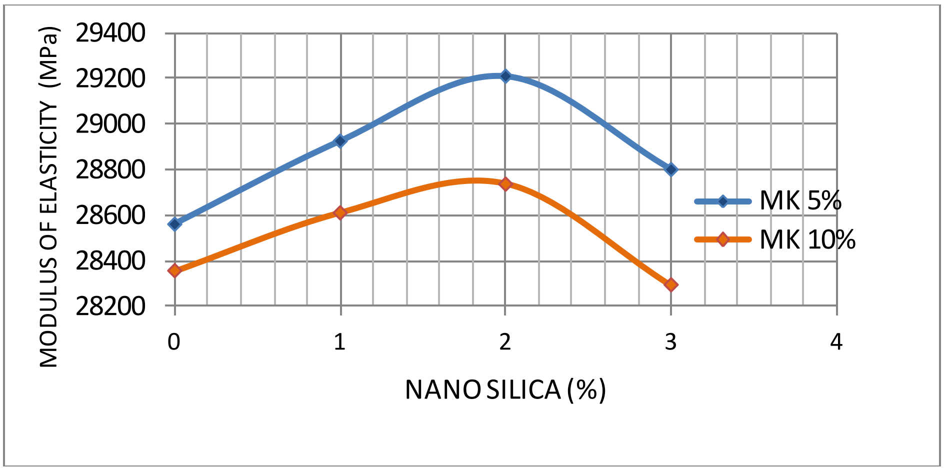


Figure 4 Variation of Modulus of Elasticity of M25 grade concrete with different percentages of Metakaolin (MK) and Nano-Silica(NS).

4.4 Flexural Strength:

The variation of Flexural strength of M25 grade concrete with increase in the Metakaolin and Nano-Silica is shown in Fig.5. The Flexural strength of M25 grade of controlled concrete is 4.51 N/mm^2. The Flexural strength of concrete initially increases up to 2% of Nano-Silica and with further increase in the Nano-Silica content the split tensile strength decreases. Similar trend is observed with the concrete containing 5% and 10% Metakaolin. The increase in Flexural strength of M25 grade concrete with 2% Nano-Silica and 5% Metakaolin combination is 7.54% compared to that of controlled concrete.

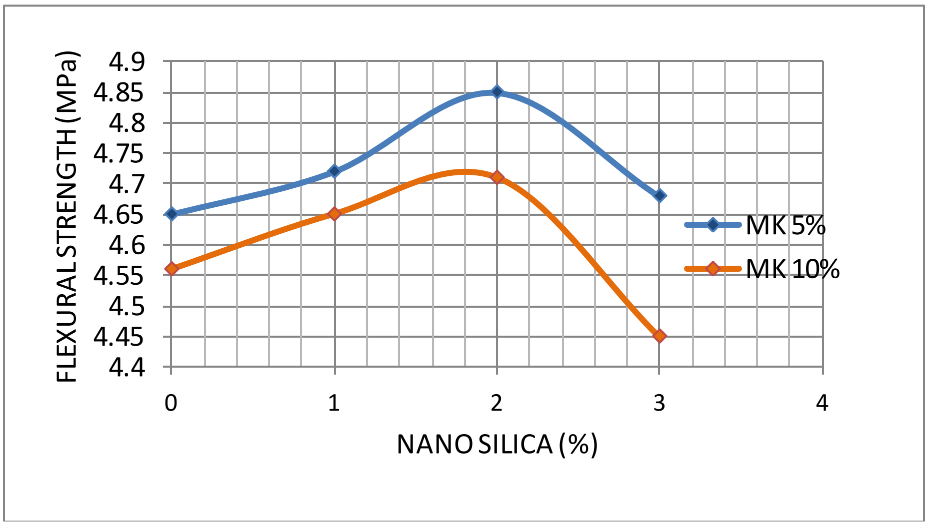


Figure 5 Variation of Flexural strength of M25 grade concrete with different percentages of Metakaolin(MK) and Nano-Silica(NS).

5. CONCLUSION :

Controlled concrete of M25 Grade is prepared and tests were conducted on standard concrete specimens to obtain compressive strength, split tensile strength, modulus of elasticity and flexural strength and then the results are compared with concrete containing various combinations of Metakaolin 5%, 10% and Nano-Silica 1%, 2% and 3% as cement replacement.

Tests were conducted on concrete specimens containing Metakaolin at 5% and 10 % as cement replacement to obtain compressive strength. Using the test results, it can be concluded that for a given Metakaolin content, the compressive strength of concrete increases as the percentage of Metakaolin is increased up to 5% and then decreases with increase in Metakaolin content. The variation of split tensile strength, modulus of elasticity, flexural strength test results of M25 grade concrete prepared with 5% and 10% Metakaolin content exhibited the similar trend. The higher surface area of Metakaolin yielded the highest strength and the fastest rate of strength gain.

Further investigation is carried out by conducting tests on standard concrete specimens to obtain compressive strength for combined replacement of cement with Metakaolin and Nano-Silica using different combinations of Metakaolin at 5%, 10 % and Nano-Silica at 1%, 2% and 3%. From the test results, it can be concluded that for a given Metakaolin content, the compressive strength of concrete increases as the percentage of Nano-Silica is increased up to 2% and then decreases. The variation of split tensile strength, modulus of elasticity and flexural strength test results of M25 grade concrete prepared with various combinations of 5%, 10% Metakaolin and 1%, 2% and 3% Nano-Silica content exhibited the similar trend.

The increase in the strength of concrete containing Metakaolin and Nano-Silica can be attributed to the availability of additional binder. Nano-Silica has high amorphous silicon dioxide content and is a very reactive pozzolanic material. As the Portland cement in concrete begins to react chemically, it releases calcium hydroxide. The Nano-Silica and Metakaolin reacts with the calcium hydroxide to form additional binder material. The availability of additional binder enhances the paste-aggregate bond which results in the concrete with Metakaolin and Nano-Silica that has improved strength properties. The decrease in the various strength properties of concrete with increase in the Nano-Silica content beyond 2% is due to the fact that the strength of the additional binder formed in the presence of Metakaolin decreases due to excessive Nano-Silica content. The combined replacement of Nano-Silica and Metakaolin exhibited increased strength properties compared to the replacement of only Metakaolin.

Hence it can be concluded that, the various strength properties of concrete can be improved by the addition of a specified percentage (2%) of Nano-Silica and (5%) of Metakaolin content.

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